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Technical Report 184

Characterizing weed management activities for archeological site preservation and grass-fire mitigation at Kaloko-Honokohau National Historical Park

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The HPI CESU is one of 17 cooperative ecosystem studies units across the U.S.

CONTENTS

i. ABSTRACT

This report summarizes recent studies conducted by the University of Hawaii, College Of Tropical Agriculture and Human Resources to improve non-native vegetation management techniques within Kaloko-Honokohau National Historical Park. The first section examines the timing of mechanical and herbicide control methods for suppressing the invasive C_4 tussock, fountain grass (*Pennisetum setaceum*). All treatment combinations initially suppressed live fountain grass cover, but the timing of treatments significantly influenced suppression longevity. We associated this timing effect with precipitation events. Mechanical treatments showed extended suppression when applied during a dry period (7.4 mm for the month), while herbicide treatments were most effective when applied during a much wetter period (74.9 mm for the month). This result encourages managers to closely monitor and exploit weather patterns when scheduling management practices to suppress fountain grass. The second section focused on the development of a Dissected Archeological Site Clearing (DASC) protocol to measure all aspects of a woody vegetation removal operation (i.e. cutting, loading and hauling) within an archeological site as a way to accurately estimate relative effort (i.e. labor resources) to complete the task. Results from six assigned sites determined that hauling the cut vegetation accounted for a considerable portion of the entire effort (46-81%). Ease of site access, adjacency to disposal site and the number of cut vegetation loads were all major determinants on the labor resources required to accomplish a task. The third section of this report utilized this DASC field data to develop a GIS modeling tool to estimate labor resources for future site-clearing efforts. Major determinants for calculating labor resources included: (i) vegetation type, area and density for estimating cutting time; (ii) the shortest distance from the arch site to load biomass on to the utility vehicle (UTV); (iii) shortest hauling distance to the disposal site. By utilizing GIS data layers from a 2010 vegetation survey and the existing UTV trail network, outputs can be estimated remotely with simple designations of the site clearing area and disposal site. The output includes an estimate of total labor resources (i.e. person-hrs) and an overall timeline (based on the number of personnel) to accomplish an assigned task. This model, in its current form, only utilizes a small data set derived from our DASC field calculations, but is designed to accept new data sets provided by field technicians in future tasks. The purpose of this tool is to facilitate management decisions by prioritizing limited resources to a wide range of site clearing activities and projecting future budget proposals more accurately.

ii. INTRODUCTION

Kaloko-Honokohau National Historical Park is located on the western shore of Hawaii Island within the district of North Kona and received the designation of National Historical Park (NHP) in 1978. The Park encompasses over 282 ha of coastal lands that include historically and culturally significant archaeological features from traditional Hawaiian settlements (National Park Service 1994). The mission of the Park is to preserve, interpret, and perpetuate traditional native Hawaiian activities and culture (16 USC 396d). Non-native, invasive plant species naturalized in the Park are a major impediment to the Park's mission in the following ways:

1. Damage and Concealment to Historical Sites
   Naturalized populations of non-native woody species, including *Prosopis pallida* (kiawe), *Schinus terebinthifolius* (Christmas berry) and *Leuceana luecocephala* (haole koa), are landscape modifiers that can permanently alter archeological sites, particularly unfortified rock walls. They are adapted to rooting in the shallow rocky substrate and can disrupt a site by anchoring to a feature and causing further damage when uprooted naturally or accidentally. High salinity tolerance is a known trait displayed by all of these species (Ewe and Sternberg 2005, Felker et al. 1981, Stamford et al. 2000), which is advantageous for utilizing the brackish groundwater as an unlimited resource in this dry climate. Kiawe and Christmas berry, in particular, become large canopy specimens that are costly to extract. These scheduled activities are more frequent when herbicide suppression is not considered as a management option.

2. Competition with Native Species
   A restoration goal for the Park is to reestablish vegetation communities consisting of native species and Polynesian introductions that were commonly used in the late prehistoric period up to the early 1800s. Pratt (1998) identified several restoration species to be included: piligrass (*Heteropogon contortus*), uala (*Ipomoea batatas*), ki (*Cordyline terminalis*), kou (*Cordia subcordata*), naio (*Myoporum sandwicense*), naupaka (*Scaevola sericea*), makaloa sedge (*Cyperus laevigatus*) and ahuawa (*Cyperus javanicus*). The adaptive traits described above for the non-native woody species may give a competitive advantage over many of these restoration selections (see Ewe and Sternberg 2005). *Pennisetum setaceus* (fountain grass) is a highly invasive, drought-tolerant grass species that is another dominant non-native representative in the Park. It can establish into large monotypic populations that have been shown to competitively exclude native species recruitment (Cabin et al. 2002, Cordell and Sandquist 2008, Thaxton et al. 2010). At the Park, fountain grass competitively occupies the depressions and fissures of the pahoehoe terrain where pockets of lithosolic soil have accumulated (Williams et al. 1995).

3. Fire Hazard
   Fountain grass is a fire-adapted species that is a present danger to visitors and personnel, particularly in high-traffic areas (Castillo 1997, Smith and Tunison 1992

National Park Service 2008). Many of the native species displaced by fountain grass may not be fire-adapted (Smith 1985, Hughes et al. 1991, Smith and Tunison 1992, Goergen and Daehler 2001, Adkins et al. 2011). Thus, fountain grass has succeeded into large, contiguous stands within the Park and across several thousand hectares outside of the Park (Castillo 1997). Furthermore, kiawe and Christmas berry contain volatile oils further contributing combustible fuel loads. (Canfield 1990).

Canfield (1990) reported 39 of 74 species (53%) within the Park to be non-native. Pratt and Abbott (1996) updated this figure to 80 non-native species out of 116 total (69%). However, the most recent vegetation inventory identified fountain grass, Christmas berry, kiawe and haole koa as the dominant populations within the Park (Cogan et al. 2011). Thus, management efforts on these problem species are likely to provide the most benefits to the Park mission. This study brings insight to conventional management practices for suppressing these species with attention to improving application techniques and resource accountability. Ultimately, this will contribute to better management decisions and strategic planning.

I. FOUNTAIN GRASS SUPPRESSION

BACKGROUND

Fountain grass is a perennial C_4 tussock grass native to Africa, which was introduced to Hawaii as an ornamental in the early 19th century and is now a state noxious weed (Wagner et al. 1999). Monotypic stands occupy tens of thousands of acres on the Big Island's leeward slopes (USDA, NRCS, 2012). It is apomictic, but exhibits phenotypic plasticity allowing for populations to naturalize across an elevation gradient from sea level to 2700 m asl (Poulin et al. 2007, Williams et al. 1995). Fountain grass is highly drought tolerant and fire adapted, capable of regenerating from minor precipitation events and fire disturbance (Adkins et al. 2011, Goergen and Daehler 2001, Poulin et al. 2007, Williams and Black 1994). Growth response and flowering stimulated by intermittent precipitation events are often referred to as 'green-up' events, with subsequent desiccation of this new growth coinciding with the next dry cycle. These desiccated foliar fractions will never rehydrate, but continue to remain attached to the clump as thatch. Annual precipitation at the Park can range from 204-751 mm with conspicuous summer precipitation events contributing to the total (Giambelluca et al. 2011). Several of these intermittent wet/dry events can lead to substantial thatch buildups (i.e. fuel loads) maintaining a perpetual, hazardous grass/fire cycle (D'Antonio and Vitousek 1992). Fountain grass occupies an estimated 19.8 ha of monotypic cover and another 89.5 ha as a major representative mixed with haole koa (Cogan et al. 2011). This encompasses up to 39% of the total management area, but covers even more area as a minor representative of the other vegetation communities, including mixes with *Acacia farnesiana* and the native *Sida fallax*.

Studies have found that uprooting individual plants by hand-pulling is a viable option for small-scale management (Smith and Tunison 1992, Castillo 1997). However, this approach has limitations within the Park because fountain grass is prevalent and any uprooting of plants near archeological features could disturb them. At the Kaupulehu Preserve (near the Park), Cabin et al. (2002) tested different methods to suppress fountain grass. The most suppressive treatment was physical clearing with a bulldozer where final percent cover was 29.3 ± 3.9%, but such a severe strategy is only practical for maintaining firebreaks. This study also demonstrated the efficacy of herbicide on fountain grass, with treatments of glyphosate demonstrating a significantly greater reduction in fountain grass cover (34.3 ± 4.3%) compared to line-trimming only (80.3 ± 3.1%).

Others have also found glyphosate products (Roundup®, Honcho® Plus, Ranger® Pro, Rodeo®, AquaMaster®, etc.) to have moderate efficacy in suppressing fountain grass. (Tunison et al. 1994, Castillo 1997, Motooka 2000, Cordell et al. 2002, Cabin et al. 2002, Castillo et al. 2007). However, glyphosate is only effective when applied during green-up events where a substantial portion of the plants are displaying actively growing foliar tissues. Leary (unpublished) demonstrated effective suppression to dormant grass with the active ingredient imazapyr, with extended suppression for over 200 days. However, similar to glyphosate, this herbicide's performance is improved when treating actively growing grass.

The goals of fountain grass suppression in the Park are to restore cultural sites and mitigate the potential for fire. Field staff use herbicide application and mechanical line-trimming to reduce fuel loads. Formulations of glyphosate and imazapyr are approved for use in the Park. This study was initiated in 2008 to determine how combinations of the two separate techniques complement each other for optimizing a suppression strategy.

METHODS

The study site was located on the southeast corner of the Park, roughly 100 m northwest of the Park maintenance yard. The vegetation cover in this area was almost exclusively fountain grass (75-88%) with some haole koa shrubs dispersed throughout (3-25%) along with areas of exposed lava rock (i.e. no vegetation cover) (5-17%). This vegetation community was contiguous beyond this experimental site for several hundred meters. Total monthly precipitation (mm) was recorded from the Kaloko-Honokohau Remote Automated Weather Station (RAWS) rain gauge between Oct '08-Apr '09 and from the NOAA Honokohau Harbor rain-gauge station data between Apr '09-Nov '09, because archived RAWS data were unavailable.

The field-plot experiment was installed as a randomized split plot design, replicated three times, with a complete factorial of untreated ("U"), chemical ("C") or mechanical ("M") treatments administered as two-part sequential applications for a total of nine different treatment combinations. The initial treatment was applied on December 11, 2008 with the subsequent assigned treatment applied on March 5th, 2009 (84 days later) to complete the sequence (Table 1). The mechanical treatment involved cutting all grass clumps with a line trimmer to a height within 5 cm of the soil surface. The chemical treatment was a broadcast application with a combination of imazapyr and glyphosate at rates of 1.12 and 1.7 kg a.i. ha^{-1}, respectively (Habitat® and AquaMaster®), at a total diluted volume rate of 187 L ha^{-1}. The final formulations included a methylated seed-oil adjuvant at 1% v/v. A total of nine main plots measuring 5 x 50 m were established by the three initial treatments (e.g. U, M and C) replicated three times, followed by the sequential treatment combinations establishing three separate split plots within each main plot measuring 5 x 5 m and spaced 1 m apart. Prior to initial treatment applications, minor representatives of haole koa were individually cut with hand tools and treated with a basal application of triclopyr (Garlon® 3A).

Table 1. Factorial matrix of sequential combinations of Untreated (U), Chemical (C) and Mechanical (M) treatments with the first letter designating the initial application on 12/11/08 establishing the main plots and the subsequent application on 04/05/09 establishing the split plots.

UU	CU	MU
UC	CC	MC
UM	CM	MM

Grass condition and percent live cover were non-destructively monitored by recording nadir (vertical) images of treatment subplots (Figure 2) once a month for eight months, beginning on March 31st, 2009 (approximately one month after the second treatment). Grass condition was defined as: “green fountain grass”, “yellow fountain grass”, “dead fountain grass” (white/grey blades still attached to base), “litter” (any dead plant material not attached), “rock”, “other” (any live plant other than fountain grass), and “unknown” (used when the pixel and surrounding area was too dark to identify). “Yellow” and “green” fountain grass categories were combined to calculate live cover. Photo points were flagged so that the same locations would be photographed throughout the project. Three photo points were collected within each subplot resulting in nine photos per treatment type and totaling 81 photos per month. Photo points were taken with a Canon™ PowerShot® G10™ digital camera and a 1m x 1m-quadrat to maintain a standard photo scale. The photographer used a ladder to ensure the entire quadrat was captured in the photo. Images were cropped to include only the vegetation within the quadrats.

SamplePoint™ 1.51 software (SamplePoint 2012) was used for image analyses to determine percent live-fountain grass cover. Sixty-four equally spaced pixels were classified in each photo according to the above seven user-defined categories. Assigning grey/white blades as “dead” may have led to an underestimate of live fountain grass cover, but was necessary in order to maintain consistency in pixel classification. Pixels classified as “unknown” and “other” were subtracted from the total to minimize bias from any non-grass vegetation, (i.e., *Leuceana*), that might have obstructed the view of fountain grass. In addition, photo plots that contained greater than 50% “other” or 50% “rock” over a majority of the months in the experiment were removed entirely from the final analysis. This deletion was made to increase normality between photo plots because areas with excessive amounts of rock or vegetative cover by other species would not represent the full potential of fountain grass to grow in that location.

Figure 1. Screenshot of a nadir image analyzed in SamplePoint. The classification area is a single pixel in the center of the crosshair. Image contains examples of "green (live) fountain grass", "yellow (live) fountain grass", and "grey (dead) fountain grass."

Percent live grass-cover was analyzed for each month with a one-way ANOVA model using R™ statistical software (R Development Core Team 2011). The live grass cover for each treatment type was compared to the untreated (control) using Dunnett's post-hoc multiple comparison procedure multcomp (Torsten et al. 2008).

RESULTS

Monthly precipitation recorded during the experiment ranged from 0-75 mm for an annual total of 286 mm (Figure 3; including the two months prior to first treatment application). This annual rainfall is on the lower end of the recorded range for the Park (e.g. 204-751 mm; Giambelluca et al. 2011). The most intense precipitation event (61 mm) occurred on the day of the first treatment application. Despite this event occurring at least four hours after the treatments were applied (the minimum rain-fast period when herbicides can be absorbed into the plant); this precipitation could have affected the herbicide activity. After this major rain event, 1 mm was recorded the following day with no precipitation occurring for the next 12 days. The second treatment in March was immediately followed by three days of recorded precipitation (1.8, 0.5, 4.0 mm, respectively) then eight days of no precipitation. Interestingly, the amount of precipitation that was recorded during the three months between the first and second treatment applications (123 mm from Dec '08-March '09) was identical to the total amount recorded over the eight months following the second application.

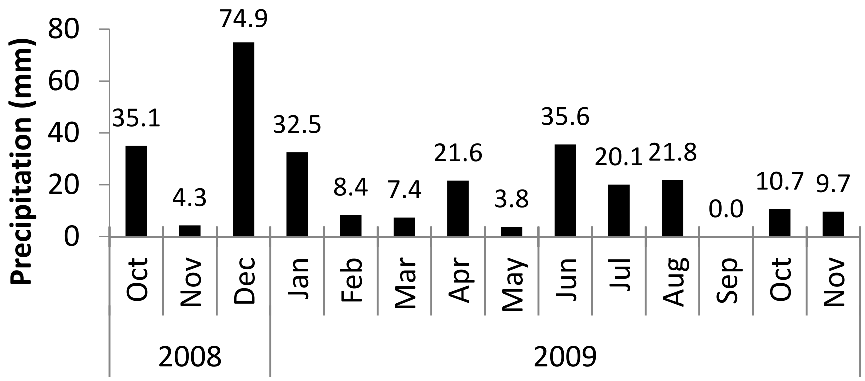
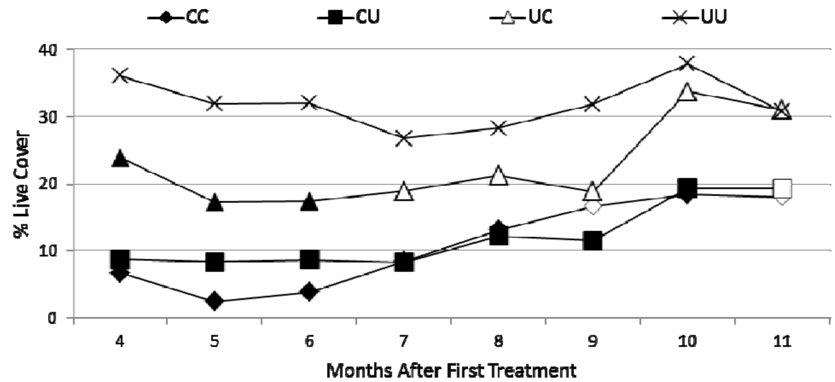


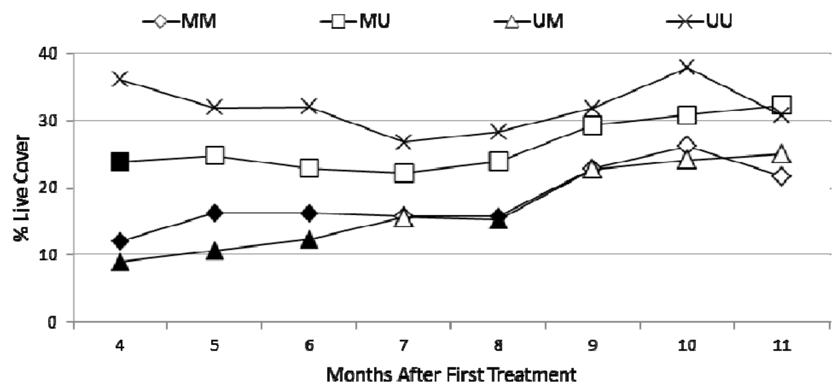
Figure 2. Total monthly precipitation (mm) recorded from Kaloko-Honokohau RAWS rain gauge Oct ’08-March ’09 and Honokohau Harbor NOAA rain gauge from Apr ‘09-Nov ‘09 recorded. First and second treatment applications took place in Dec ’08 and March ’09, respectively.

The untreated (UU) treatment maintained live grass cover that never dropped below 25%, but also never exceeded 40%, while the chemical (C) and mechanical (M) treatments were able to suppress live grass cover to less than 20 and 25%, respectively, eleven months after the first treatment (Figure 4). Complete suppression was not achieved for any of the treatment combinations. However, all treatments did exhibit significant levels of suppression at time intervals that extended up to seven months after the second treatment application for one of the chemical treatments, while as short as only one month for one of the mechanical treatments (Figure 4A and B). Both CC and CU treatments, receiving December herbicide applications, were superior to the UC treatment applied in March (Figure 4A). There were no substantial differences between CC and CU and both maintained less than 10% live cover for up to seven months after the first application, but started to show increases at six months. On the other hand, MM and UM both received March line-trimmer applications that were superior to the MU treatment received in December, but again were not substantially different from each other (Figure 4B). In this case, only the UM treatment was able to suppress live cover to below 10%, which occurred at one month after the March treatment application. All chemical/mechanical treatment combinations showed significant suppression, but were not superior to the chemical treatment alone (Figure 4C).

A



B



C

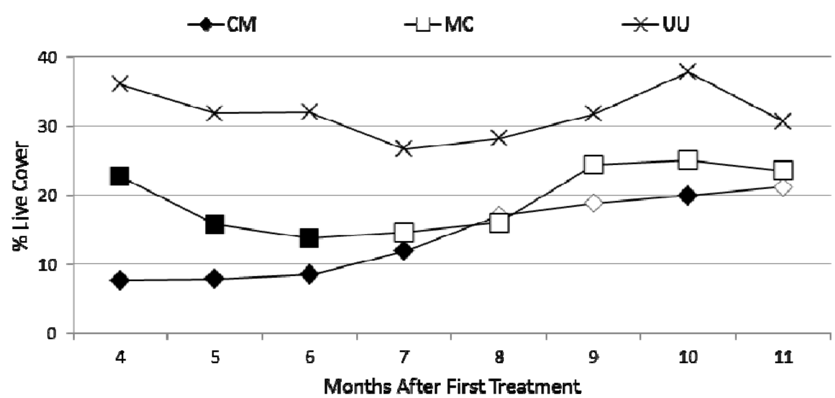


Figure 4. Mean percent live cover recorded monthly for (A) Chemical sequence treatments CC, CU and UC; (B) Mechanical sequence treatments MM, MU and UM; (C) Chemical/Mechanical combination sequence treatments CM and MC. All compared to the Untreated UU. X-axis is months after first treatment. Filled points represent significant difference (P<0.05) from the UU treatment of that month.

Differences in mean live grass cover based on the sequence of the applications (i.e., December or March) were significant for both the chemical ($p = 0.027$, df = 13) and mechanical ($p = 0.039$, df = 16) treatments. The C treatments were more effective as a December (high precipitation) application, while the M treatments were more effective as a March (low precipitation) application (Figures 3 & 5).

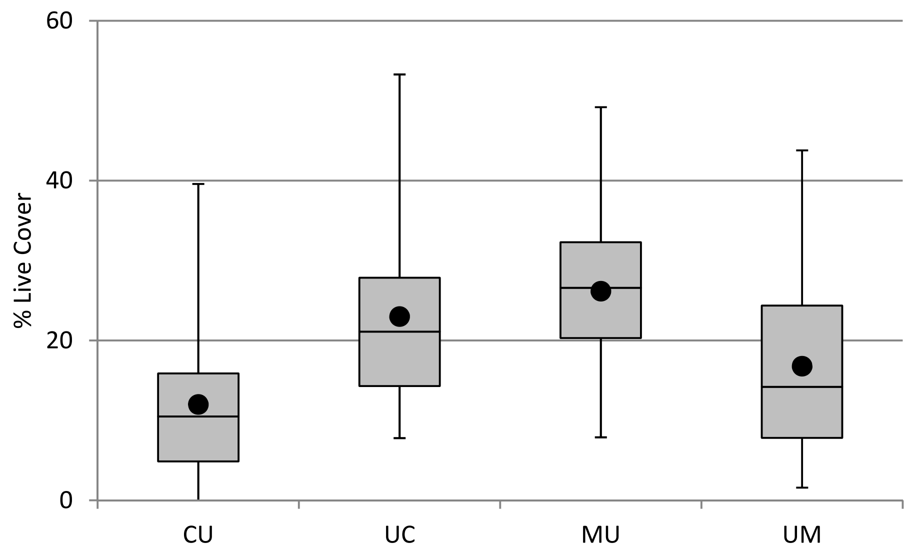


Figure 5. Percent live cover following chemical (CU and UC) and mechanical (MU and UM) treatments with mean (point), median (line), 50% range (box) and 100% range (whiskers) of all recorded data points from April to Nov ’09. Initial treatments (CU and MU) applied Dec ’08 when monthly precipitation measured 74.9 mm and sequential applications applied March ‘09 when monthly precipitation measured 7.4 mm (UC and UM applied), respectively.

DISCUSSION

Both chemical and mechanical techniques can be effective in suppressing fountain grass, and become complementary activities with the proper sequence and timing. The chronology of this study started with a modest wet period followed by an intermittent dry period that was conducive to a more effective herbicide application early and a mechanical application late. In fact, there was no added benefit from a second application of either technique (MM, CC) when compared to the single treatment applied in those best sequence (UM, CU). There was also a significantly longer suppression period of the CM combination over MC. We note that the optimal conditions for an herbicide application (wet) are not the same as those for a mechanical mowing application (dry). Thus, on many occasions the MC sequence may be the more effective approach particularly if initiating management during a dry period in anticipation of a wet period.

Fountain grass is tolerant to a wide range of environmental conditions, in particular, drought stress (Poulin et al. 2007, Tunison et al. 1994, Williams et al. 1995). However, it is also quite responsive to available moisture (Williams and Black 1994, Poulin et al. 2007). Both photosynthetic activity and biomass production of fountain grass have been shown to dramatically increase with augmented moisture (Poulin et al. 2007, Williams and Black 1994). Thus, drought tolerance is a trait that supports survival and persistence of fountain grass in arid climates with the responsiveness to intermittent precipitation being a complementary driver of invasiveness (Goergen and Daehler, 2001, Poulin et al. 2007). Poulin et al. (2007) showed over 4-fold increase in biomass production of common garden plantings in Southern California augmented monthly with 40 mm precipitation. In our study, only December exceeded this amount at almost double this rate (e.g. 74.9 mm), which, incidentally, was also the time interval that encompassed the first treatment application. Moreover, only five other months exceeded 20 mm precipitation, not including March, which was the time interval encompassing the second application (see Figure 3). This study does not provide data for interpreting threshold precipitation-levels necessary to promote fountain grass growth.

Herbicide treatment efficacy is typically maximized when plants are actively growing. In a previous study, Leary (unpublished) identified imazapyr to show residual activity on dormant fountain grass, but was also a sub-lethal application influenced by the less than ideal conditions. While the herbicide applications of this study were not considered to be highly effective, the significantly higher level of suppression during the wetter period supports the recommendation to treat actively growing plants (i.e. green-up events) and is consistent with other reports referenced in Pratt (1998). The reason for low efficacy may have been due to the largest precipitation event occurring several hours after the initial application, which potentially diluted the herbicide residue on the treated plants. Complete failure of the herbicide might have occurred if the treatment only consisted of the glyphosate active ingredient, which does not have residual activity. On the other hand, precipitation seemed to have the opposite effect on the mechanical mowing treatments. Grass recovery was observed following the December treatment, while the March treatment showed extended suppression coinciding with the subsequent dry months. Another anecdote observed in the field was how hard it was to cut green grass, while cutting desiccated thatch was a much easier task. Although mowing is not a technique designed to terminate the species, it was comparable to the herbicide treatment in this study, likely due to the suppressive effects of the dry weather conditions. Furthermore, it should be noted that mechanical mowing is a superior technique for physically reducing fuel loads as a fire mitigation practice ancillary to suppressing growth and competition. The combination was expected to work better than what was demonstrated, but we still conclude these two techniques to be complementary.

Recommendation: Although the herbicide application was superior to mechanical applications, we still recommend the combination of the two in a sequence determined by the condition of the grass. With mechanical operations, fuel suppression is much more immediate (e.g. reducing thatch height). Furthermore, fountain grass dormancy and desiccation is a much more prevalent phenomenon at the Park, conducive to more opportunities to administer suppressive applications. However, herbicide application is much more efficient and should be utilized when opportunities are presented. Park staff should observe current and projected precipitation patterns within the park when planning fountain-grass management efforts. We speculate that small green-up events may occur within several days after a one-week 10 mm precipitation event, but would peak with several events adding up to monthly precipitation >40 mm. Based on our observations, green-up events are transient and plants can go dormant several days later. The ability to monitor quantifiable trigger events (i.e. precipitation) could lead to customized management strategies with better decisions on how and when to integrate herbicide and mechanical applications. New monitoring protocols are needed for monitoring green-up events at the Park. For instance, questions that still need to be answered include: (i) what are single precipitation event thresholds that trigger green-up, (ii) what is the response phase where the peak growth activity is most susceptible to an herbicide application and (iii) how does green-up longevity relate to cumulative precipitation. The basic approach would involve the installation of strategically placed rainfall collectors adjacent to semi-permanent monitoring transects and/or photo points. A remote sensing approach could be used to analyze weekly/monthly satellite imagery and could complement field monitoring with a more sophisticated method of calculating spatial and temporal parameters of green-up events, and may also be used in measuring suppression efficacy of managed areas.

II. DISSECTED ARCHEOLOGICAL SITE CLEARING

BACKGROUND

Since the establishment of the Park in 1978, many resources have been dedicated to vegetation management for protecting archeological features. These efforts continue today and are most reliant on physical removal actions, which are labor intensive. To better understand how labor resources are applied in these vegetation removal activities, we developed a Dissected Archeological Site Clearing (DASC) protocol to independently record each aspect of an operation from cutting to hauling. This protocol was then implemented at six different archeological sites towards development of a model for estimating labor resources for future site clearings.

METHODS

Six archeological sites were cleared from 2009-2012 mostly by a two-person crew (on one occasion D13-34 clearing was achieved with a large volunteer crew) using DASC protocols (Table 2). Prior to recording any vegetation removal activities, the boundaries of each site encompassing the archeological features were delimited and mapped, along with establishment of semi-permanent photo points. Features were made visible with flagging to ensure that none were disrupted during the removal process. No less than four photo points were positioned around the perimeter of the site and one panoramic photo was taken from the center of the site. The site was delimited by a perimeter that was established no less than five meters from any one of the designated features. In certain circumstances, the perimeter may have been extended to accommodate removal of other nearby vegetation encroaching upon the site.

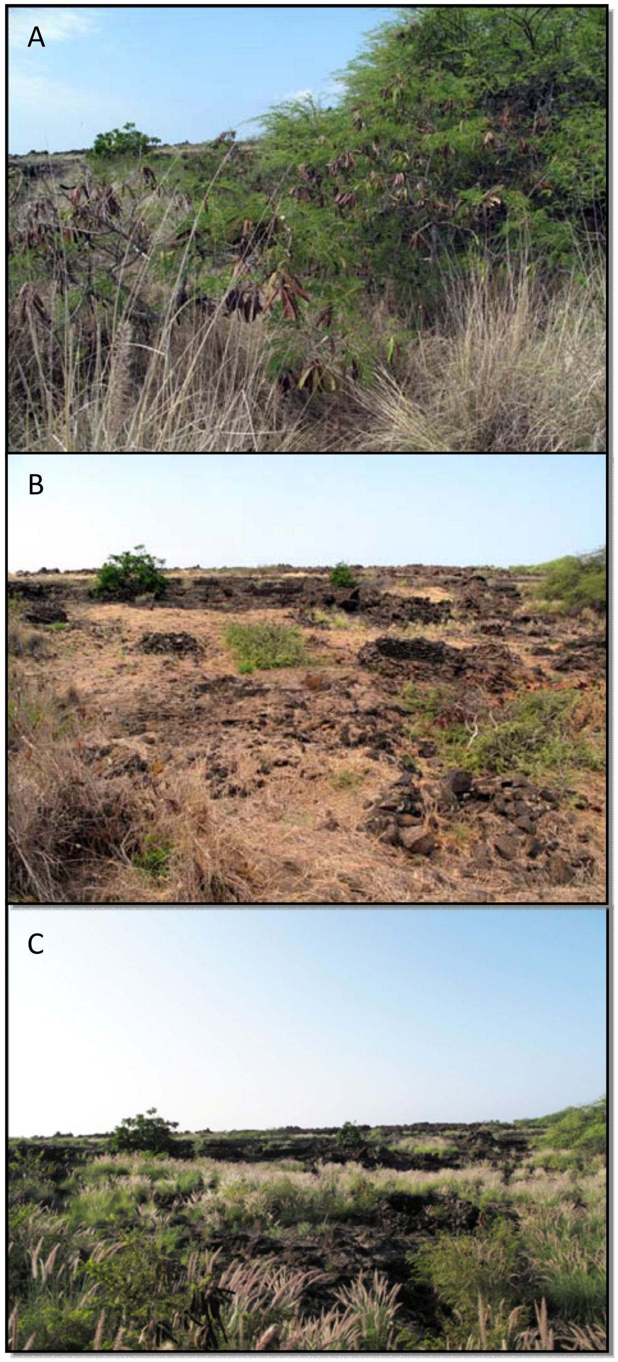


Figure 6. Photos of a clearing-site (A) before clearing (B) immediately after clearing (C) 6 months after clearing. Photos were taken from the same photo point facing the same direction.

Table 2. The six archeological sites cleared during the study.

Site	Area (m^2)	Start Date	End Date
D13-10	1,034	Jan-2009	Jul-2009
D13-58	2,917	Sep-2009	Jul-2010
D13-40	244	Dec-2010	Mar-2011
D13-39	234	Dec-2010	Apr-2011
D13-32	756	Apr-2011	Jul-2011
D13-34 "C"	999	Jan-2012	Jun-2012

Time was recorded with a stopwatch for each activity from start to completion with stops in between when the activity was halted (i.e. break). Net cumulative time was reported for each activity. All minutes and hours reported herein are "person-minutes" and person-hours". Cutting and hauling procedures were determined by the vegetation type and size. Typically trees and shrubs were cut using a chainsaw and hauled from the site using a utility task vehicle (UTV) while grasses were cut with a line-trimmer, but was not removed from the site. Some sites required additional activities such as the use of pole-saws in order to limb larger trees before felling. Vegetation cutting commenced by order of vegetation type and size: (i) small-class kiawe (<20 cm diameter at breast height (DBH)), (ii) small-class Christmas berry (< 20 cm DBH), (iii) large-class Christmas berry (>20 cm DBH), (iv) grass suppression, and finally (v) large-class kiawe (>20 cm DBH), if necessary. This order was maintained in our trials for comparative purposes. Other DASC protocols included cutting stumps to within 5 cm of the ground, cutting branches to approximately 50 cm for consistent ease of hauling, and piling cut vegetation no more than 50 cm high for the same reason. Cut tree stumps received an herbicide application (triclopyr at 1-2 lbs. active ingredient per gallon). Cut material were stacked and readied for hauling. If piles were located near UTV loading sites, then they were free loaded. If piles were greater than 5 m from the UTV, they were delivered to the UTV in a 0.12 m^3 receptacle (32-gallon trash can). Vegetation could often be stacked above the height of the cargo bed, so visual estimates of the total number of cargo beds full of vegetation were made for each UTV load. For example, if vegetation extended twice the height of the cargo bed, then the payload was equal to two UTV beds of vegetation. UTV payloads were recorded each trip because they contained varying combinations of logs and brush; however, we estimated an average payload to be 0.63 m^3. Grasses were also cut within 5 cm of the ground and spot sprayed with herbicide (glyphosate or imazapyr at 0.04-0.08 lbs. ai/gal; 2% v/v). This step was usually the last activity that took place 2-3 weeks after cutting and hauling the woody components from the site.

The thick vegetation cover in site D13-34 made it too difficult to perform a pre-clearing survey or to remove vegetation components in the order of the DASC protocol. Instead, inventory and vegetation measurements were collected concurrently with removal activities. A grid was established within the D13-34 clearing site to keep track of the vegetation inventory and to help estimate removal time. A total of 31 sections (5 x 5-m; ca. 775 m^3) divided up the stand. Prior to removing a section, average height and a visual estimation of percent cover were recorded. Counts of individual plants per grid-square were recorded if plant occurrence and growth form allowed. In addition, all basal diameters of vegetation were recorded, excluding basal diameters <10 cm for Christmas berry and kiawe. Time requirements for cutting and hauling of vegetation at D13-34 were recorded separately within each grid square. Chemical treatment of cut stumps was also included in cutting time.

RESULTS

D13-34

The vegetation covering Archeological site D13-34 area "C" consisted almost exclusively of Christmas berry and grew in dense, horizontal vine-like branches 2-4 m in height from the ground (e.g., see Figure 7).

The percent cover of Christmas berry over the area, before clearing, was 84% with an average height of 2.5 m (range 1-4 m). Besides the other exotic species, there were also some native species, and Polynesian introductions represented: *Thespesia populnea* (milo), *Scaevola taccada* (naupaka), *Morinda citrifolia* (noni), and *Capparis sandwichiana* (maiapilo). None of these contributed >1% cover (Table 3).

Mean cutting time among the 31 sections was 3.6 ± 1.6 min/m^2 (mean ± SD), with variability mostly along the edges of the infestation where it inherently thins out. Excluding these edge sections, mean cutting time increased to 4.2 ± 1.3 min/m^2. Christmas berry removal was 93% of the total cutting time.

Each 5x5 m grid square contained an average of 2.23 ± 1.04 m^3 of vegetation translating into an average of 3.4 UTV loads. At distances between 5-30 m, loading time (i.e., time required to move the vegetation from the cut pile to the UTV bed) was positively correlated with increasing distance (R^2= 0.54) between the UTV and the pile (data not shown). On average, loading one UTV took 34.7 person-minutes with 1.0 additional minute for every meter of distance between the pile and the UTV. This trend was observed using the receptacle for hauling brush and free loading logs. When distance between the piles and UTV were short enough to free-load brush into the bed of the UTV (i.e. <5 m), loading time was greatly reduced, averaging 16.6 ± 7.3 person-minutes per load.

UTV travel-distance to the disposal site was 986 meters and took 10.3 ± 2.5 person-minutes round trip. A total of 110 UTV loads hauled away an estimated 73.4 m^3 of vegetation to the disposal site. Unloading vegetation at the disposal site took an average of 6.3 ± 2.0 person-minutes per load, for an added 11.6 person hours. For this site, UTVs traveled a total of 217 kilometers in 37.7 person-hours. Total loading/hauling time was 118 hours; 71% of the total time (Table 4). Travel between the Park maintenance yard and the clearing site (not included in

Table 3. Plant species found within clearing boundary of site D13-34.

Species	Status	Max Ht (cm)	# of individuals	Sum Dia. (cm)	% coverage
Christmas berry	A	400	74*	1868.5*	84%
Kiawe	A	240	2*	16.75*	2%
Bittermelon *M. charantia*	A	NA	2	NA	<1%
Maiapilo *C. sandwichiana*	E	225	2	17.7	<1%
Naupaka *S. taccada*	I	120	NA	NA	1%
Noni *M. citrifolia*	P	470	14	67.6	<1%
Milo *T. populnea*	P	700	3	32.1	3%
Fountain grass	A	120	NA	NA	10-25%**

Notes: Status A = Alien, E = Endemic, I = Indigenous, P = Polynesian introduced:
* includes only basal diameters >10 cm
** approximately 100m^2 of 10-25% grass cover on eastern side of the grid.

DASC timetable) added another 66 ± 10 person-minutes of UTV operation per day when using the Mamalahoa Trail and Hu'ehu'e Ranch Road. The Ala Kahakai Coastal Trail was faster, averaging 40 ± 5 person-minutes roundtrip.

Site D13-10

Clearing activities for site D13-10 began in January 2009. The northern portion of the site was cleared in a previous activity months earlier, so the southern portion was the focus of this particular clearing activity. A rock wall feature outlined the cultural site. The total cleared area, including a 5-m buffer around the rock wall, was 1034 m^2. UTV access was within 5 meters, allowing for vegetation to be free loaded.

Small and large class Christmas berry was by far the dominant vegetation and access to the dense thicket impeded progress (see Figure 7). In total, 48 person-hours were required to remove this species, which accounted for 72% of all vegetation clearing and 40% of the total time (Table 5). Loading/hauling of the vegetation required 55 person-hours (45% of total). In total, this site was cleared in 14 work days within a six-month period that ended in July 2009.

Table 4. DASC timetable and order of clearing for site D13-34. Fountain grass not included in loading/hauling.

DASC Order	Person-Minutes	Person-Hours	Person-Work Days
Christmas berry	2761	46	6
Kiawe	61	1	0.1
Fountain grass	156	3	0.3
Loading/Hauling	7062	118	15
TOTAL	10,040	168	21.4

Table 5. DASC timetable and order of clearing for site D13-10.

DASC Order	Person-minutes	Person-Hours	Person-Work Days
Tagging trees	66	1	0.1
Small kiawe	455	8	1
Small Christmas berry	1371	23	3
haole koa	122	2	0.3
Large Christmas berry	1488	25	3
Large kiawe	172	3	0.4
Other	218	4	1
Loading/Hauling	3298	55	5
TOTAL	7190	121	14

Figure 7. Growth form of dominant Christmas berry observed impacting many of the sites

Site D13-58

Clearing activities for D13-58 began on September 2009. This particular site was the largest, encompassing 2917 m^2, with 14 individual archeological features identified. Due to its size, and issues with time, we couldn't clear cut one large swath; instead we had to clear pockets around the features. Kiawe was the dominant species at this site, taking 55 hours to clear, which was equivalent to 45% of the vegetation clearing and 16% of the total time (Table 6). Loading/hauling of the vegetation required 218 person-hours (64% of total). This site was completed in 42 work days within a 10-month time period that ended July 2010.

Table 6. DASC timetable and order of clearing for site D13-58.

DASC Order	Person-minutes	Person-Hours	Person-Work Days
Small Christmas berry	753	13	2
Small kiawe	876	15	2
Large Christmas berry	50	1	0.1
Haole koa	985	16	2
Large kiawe	2423	40	5
Fountain grass	1607	27	3
Other	577	10	1
Loading/Hauling	13085	218	27
TOTAL	20,356	340	42

Site D13-32

Clearing activities commenced in July, 2011 and were completed 4 months later in August. Clearing activities mainly involved felling and hauling a large kiawe tree, which was 97% of the 12 work-days required to complete the task (Table 7).

Site D13-39

Site D13-39 was the smallest of the clearing sites at 234 m^2. This site was another example of a removal operation of a single large-class species (Christmas berry) that was completed in 6 work days. It should be noted that 79% of the time was dedicated to hauling the materials away from the site, which is due to long distances to the UTV and the disposal site (Table 8).

Site D13-40

Site D13-40 was the second smallest site and again dominated by large-class specimens, in this case Christmas berry and kiawe. This was also another situation where hauling time was a substantial amount of the effort at 82% of the total time (Table 9).

Table 7. DASC timetable and order of clearing for site D13-32.

DASC Order	Person-minutes	Person-Hours	Person-Work Days
Large kiawe	2364	39	5
Fountain grass	101	2	0.3
Loading/Hauling	3231	54	7
TOTAL	5,696	95	12

Table 8. DASC timetable and order of clearing for site D13-39.

DASC Order	Person-minutes	Person-Hours	Person-Work Day
Large Christmas berry	479	8	1
Fountain grass	72	1	0.1
Other	26	0.4	0.05
Loading/Hauling	2204	37	5
TOTAL	2,781	46	6

Table 9. DASC timetable and order of clearing for site D13-40.

DASC Order	Person-minutes	Person-Hours	Person-Work Day
Large Christmas berry	458	8	1
Large kiawe	202	3	0.4
Loading/Hauling	2941	49	6
TOTAL	3,601	60	7

DISCUSSION

Leaving the vegetation at the site can continue to be an obstruction to archeological features and also cause a fire hazard, making this practice non-compliant with Park policy. With that in mind, removal of vegetation from the sites is a substantial financial obligation. In our assessments, loading and hauling activities accounted for 46-81% of the total time among the DASC sites, suggesting that most of the improvements in efficiency may result from changes in these activities. The capability to park the UTV within 5 m of the clearing site allowed for free-loading vegetation was a major time saver. However, to protect cultural and natural resources, UTVs must remain on access trails. It should be noted that timetables for each clearing site are only specific to the physical acts of cutting and hauling vegetation. Secondary activities (e.g. equipment maintenance, repair, hydration breaks, travel between maintenance yard and site, travel between park and office, cleaning vehicles, etc.) were not included in the timetables, but we estimated that this could take up to an additional four hours each day. For instance, when a site is located on the north side of the Park, travel from the Park maintenance yard to the clearing site each day consumed over one hour per person, One solution may be to consider satellite areas for temporarily securely storing equipment for more efficient access to some of the remote locations on the Park. For site D13-34, being able to temporarily store the UTV and cutting equipment near Kaloko Pond could have saved up to 60 person-hours (i.e., 36% of total effort). Thus, labor estimates should double when estimating *total workdays* needed to clear a site.

Recommendations: All of these sites were dominated by large-class specimens that required the majority of labor resources for removal. These sites will require follow-up vegetation control activities. Although follow-up control was not accounted for in this study, we anticipate that rescheduling maintenance when the vegetation is smaller will be a more efficient use of labor resources. In the following section, DASC time records from these were analyzed and a model was constructed to predict time requirements for future removal efforts pertaining to large-class dominated vegetation.

III. DASC TIME-PREDICTION MODEL AND GIS TOOL

BACKGROUND

In our Dissected Archeological Site Clearing (DASC) assessments we identified both spatial and temporal influences on labor resources required to complete an activity. We utilized these data to develop a DASC time-prediction model as a custom ArcGIS® tool for estimating labor resources (i.e person-hrs) to accomplish site clearing tasks. This model is limited by the data currently available, but accuracy is expected to improve as data are generated in future site clearing activities. This model specifically focuses on predicting time elements for cutting and hauling activities, but does not consider other ancillary work activities that are necessary to maintaining functionality of an operation (i.e. equipment maintenance).

METHODS

Five separate variables were chosen from the six DASC sites as model predictors. These variables included (i) type of vegetation removed, (ii) area of vegetation removed, (iii) density of vegetation removed, (iv) hauling distance by UTV, and (v) average loading distance by walking. The dominant vegetation type of each site was matched with the categories constructed for the Park's vegetation map and database (Cogan et al. 2011). From the six archeological sites, four vegetation classes were selected (Table 10). In addition, we used three density groupings described in the Park's vegetation database (Cogan et al. 2011). These density intervals included 10-25%, 25-60%, and >60% cover.

In some cases, discrepancies were observed in the assigned vegetation classes of the database to what was actually observed at the sites. Thus each of the sites were revisited to validate or reassign the vegetation class and also to estimate area and density for each vegetation class using hardcopies of 2006 *Quickbird* satellite imagery and available DASC information. Area boundaries were estimated by hand-drawing on imagery hardcopies and then digitized in ArcGIS® using the original GPS collected boundaries of each site-clearing as a reference. With DASC cutting-time records subdivided by vegetation species, some sites provided multiple observations for use in the cutting model (Figure 9). In addition, the clearing effort at D13-58 (e.g. the largest site with 14 individual archeological features) contained nine distinct sub-sites, each recorded separately and providing additional observations for this model building exercise. The area for each sub-site was then calculated in ArcMap® 10.

Table 10. The vegetation classes cleared from the six archeological sites.

Dominant Species	Veg Type	Class Code
Fountain grass	Herbaceous	H_PESE
Haole koa/fountain grass	Shrubland	S_LEPE
Christmas berry	Woodland	W_SCTE
Kiawe	Woodland	W_PRPA

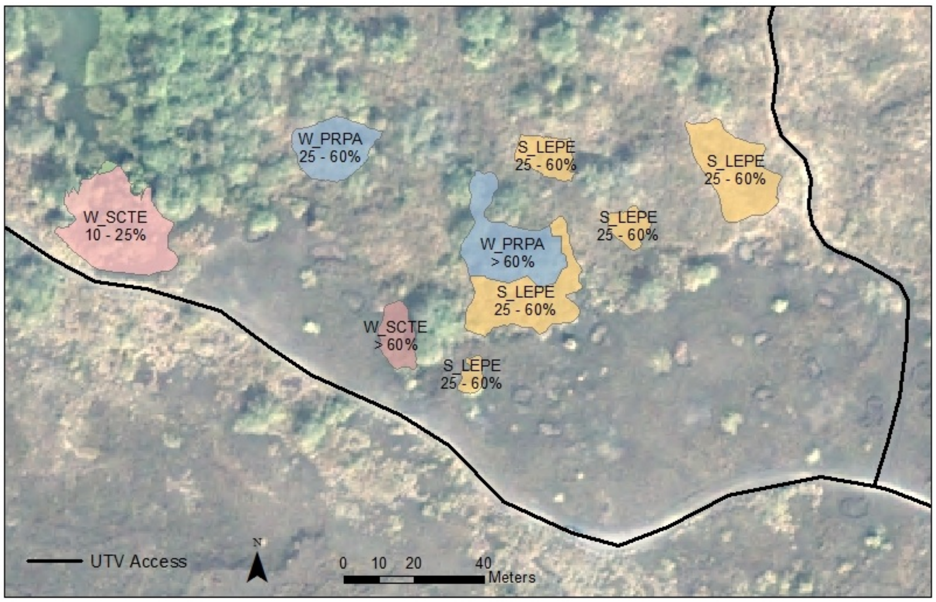


Figure 9. Site D13-58 encompassing nine distinct sub-sites with assigned vegetation and density classifications. See vegetation class codes in Table 9.

Hauling distance was calculated for each site using the Network Analyst system toolset in ArcMap® 10 that created a network dataset using the Park's UTV access trails for calculating the shortest distance along the network between the clearing and disposal sites. Average loading distance was calculated by measuring the distance between the center point of a vegetation class and the UTV loading location of each clearing site. This calculation was performed using the "Feature to Point" and "Near" system tools in ArcMap®.

Originally, two multiple regression statistical models were constructed, one using cutting time as the response, and the other using hauling time (loading included) as the response. However, the number of predictor variables needed in the cutting model was too large to accurately select an appropriate model. Therefore, a simplified method was used for the cutting data in which the average cutting time per square meter was calculated for each available vegetation class-density. A multiple regression was conducted for the loading/hauling model to simultaneously evaluate three continuous variables (*area to be cleared, average UTV distance,* and *average walking distance*). The categorical variables (*vegetation class* and *vegetation density*) were largely reduced or removed to accommodate the limited sample size. All statistical tests were performed using R statistical software (R Development Core Team 2011).

We developed a custom GIS tool to calculate predictor variables for proposed clearing sites. Each step to calculate the predictor variables, described above, was linked into one process using ArcGIS Model Builder (Figure 10). The final step of the process was to incorporate the calculated predictor variables for the proposed clearing site into the statistical models to estimate cutting and hauling times.

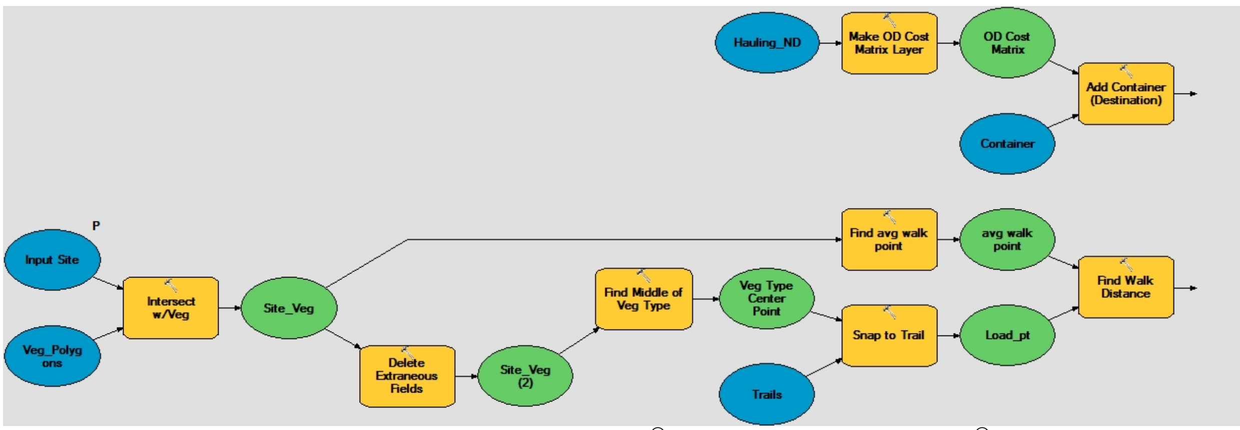


Figure 10. Subset of processes for custom ArcMap® tool designed in ArcGIS® model builder.

RESULTS

Mean cutting rate was calculated for each *vegetation class + density* recorded (Table 11). The kiawe vegetation class required the most time to cut at 4.80 ± 2.18 min m^{-2}. Christmas berry vegetation class, at the same density, averaged only 2.74 ± 0.82 min m^{-2}. The haole koa/fountain grass vegetation class at 10-25% density averaged 1.44 ± 0.50 min m^{-2} to cut. Finally, the fountain grass vegetation class averaged 0.76 ± 0.05 min m^{-2} to cut with line trimmers.

Hauling times were not broken down by species in the DASC time-record. Furthermore, fountain grass was left on site, so there were no *H_PESE* observations. Thus there were fewer total observations for the hauling data than the cutting data. The *Vegetation density* variable was removed from the hauling model because density categories were too similar to vegetation classes (e.g. all *S_LEPE* records were also in the *25-60%* density category) causing multi-co-linearity problems in the model. Finally, the woody vegetation classes "*W_PRPA*" and "*W_SCTE*" were consolidated into one group because hauling time was not significantly different between them. These modifications resulted in two vegetation classes: *S_LEPE* and a

Table 11. Mean cutting time (± SD) for the four main vegetation classes removed at DASC clearing sites.

	Mean Cutting Time (min m^{-2})	SD (min m^{-2})
H_PESE		
10 - 25%	0.53	NA
25 - 60%	0.76	± 0.05
S_LEPE		
25 - 60%	1.44	± 0.50
W_PRPA		
> 60%	4.80	± 2.18
25 - 60%	1.68	NA
W_SCTE		
> 60%	2.74	± 0.82

Table 12. ANOVA and results for the hauling model

Source of variation:	df	*F*	*P*
HAUL TIME:			
Area cleared	1	374.546	<0.001
Vegetation Class	1	53.131	0.005
mean Hauling Distance	1	48.035	0.006
mean Loading Distance	1	6.512	0.084
Residuals	3		

class containing both *W_SCTE* and *W_PRPA*. *Area cleared*, *vegetation class*, and *mean hauling distance* were significant (P<0.05), while *mean loading distance* was not significant (P = 0.084) (Table 12).

The recorded DASC parameters for site D13-34 were input to the model to test the confidence intervals (Table 13). The upper and lower limit of the total clearing was ± 37 person-hours from the mean. The experimental range for the hauling and cutting models included areas between approximately 100-1,000 m^2, UTV hauling distances between approximately 150-1000 m, and mean loading distances between 15-50 m.

Table 13. Example of the model's 95% confidence interval for D13-34.

	Inputs (hrs)	Lower limit (95%)	Upper limit (95%)
Cutting	47	24	67
Hauling	118	103	133
Total	164	127	200

DISCUSSION

The Park's vegetation map and database lists only three categories for cover density (Cogan et al. 2011), which may be a limitation to the accuracy of the model, particularly for vegetation classes under the broadest category of 60-100%. More precise ground-truth measurements (i.e. total basal area or stem density) could improve cutting time estimations, but may be unjustified as a time-consuming activity contradicting the overall effort.

The access-trail network GIS layer is accurate and useful to estimating hauling times, but more accurate measurements of loading distances will improve model results. This can be easily recorded at the site while conducting clearing activities. Further consideration should also be given to predetermining acceptable loading sites for each grid section with the shortest loading distances to the connecting trail network. With loading and hauling activities requiring substantial resources, this seemingly modest aspect of actually determining where to park the UTV, should increase efficiency particularly on larger sites.

Currently, the model is designed to utilize the most recent Park vegetation map (Cogan et al. 2011) for roughly estimating labor resources to clear sites. The ArcMap® custom tool will only calculate person-hours for the vegetation types and densities identified in Table 11. Therefore, it is important to make sure that these attributes are defined correctly within the vegetation map before running the ArcMap® tool for a proposed clearing site. Sometimes, the map did not agree with what was actually removed at some of the clearing sites. For instance, for a few of the sites, kiawe was listed as the major vegetation class on the map when Christmas berry was actually the species removed from that area. This potential misidentification was addressed in the Cogan et al. (2011) contingency table but still needs to be corrected (edited in a GIS) within the vegetation map when encountered. More often, the map misidentified the Christmas berry class as a *Thespesia populnea* (milo, Indian tulip, Pacific rosewood) class, which was not addressed in in the contingency table. Therefore, ground-truth activities to validate vegetation classification are advised when calculating labor resources. We also advise managers to continue adding data for building a more robust model to improve accuracy in predicting outputs. This process starts with delimiting the entire area encompassing all of the archeological features designated for clearing. Subsequent designation of sub-sites may be warranted for larger areas with multiple features. These activities can be accomplished by circumnavigation with GPS and installation of temporary markers, where possible. If the intent is to maximize the utility of the map and data base products, we recommend maintaining the current classification system, but allowing for modest reassignments of vegetation class and density categories that have been corrected with ground-truth activities. The capability to determine the number of payloads per unit area of a clearing site should be one of the most important predictor variables in accurately pre-determining resource needs. Our current approach is to adopt a measured grid system for systematically removing portions and accurately accounting for the number of payloads relative to the number of grids. We speculate that vegetation class may be a negligible influence, unlike the cutting activities. We recommend that along with designating sub-units of archeological features, that a more comprehensive system of sub-units (i.e. grid system) also be established for predetermining a systematic approach to clearing the entire area. While conducting clearing activities, time records should be kept for cutting, loading and hauling of each sub-unit, and including the number of payloads. The most accurate way to record these activities is with a GPS recording a track with timestamps.

This model is designed to support management decisions for budgeting resources, monitoring progress, and identifying where efficiency can be improved. Managers should bear in mind, however, that the model is constructed from a limited sample set and is valid only within the experimental range it is based upon; complete variability of vegetation types and cover densities may not have been captured. Additionally, secondary vegetation clearing activities are not captured. It may also be pertinent to consider variability among the field staff, such as team size (e.g. 2-person vs. 3-person crews) and work effort (e.g. fast vs. slow). Finally, secondary tasks such as equipment preparation and maintenance, along with travel distances between site and maintenance yard may be significant fractions of the total required labor resources. Nonetheless, this model is a first step towards predicting future clearing efforts at Kaloko-Honokōhau National Historical Park by examining the distinguishing aspects of an operation that have inherent implications on labor resources.

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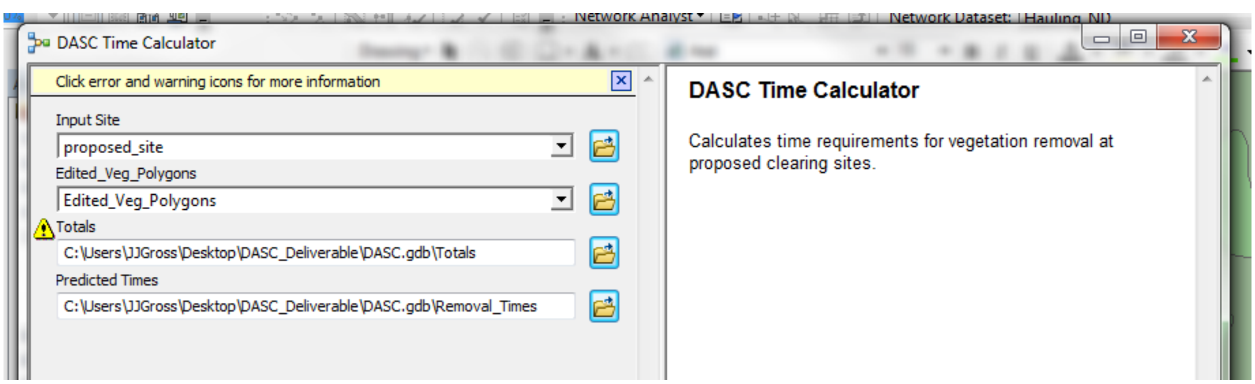
APPENDIX 1

Installing the DASC TIME-PREDICTION MODEL AND GIS TOOL (Requires ArcMap 10 (or later version) and Network Analyst Extension)

1. Download zipped DASC deliverable file. Extract to any location on your computer.
2. Open DASC_Deliverable folder and double click DASC_Document (ArcMap Document) to open the package in ArcMap.
3. Map should display vegetation and roads near Kaloko fishpond.
4. Select Customize > Extensions from the menu. Check Network Analyst if not already checked.
5. Open ArcToolbox window (if not already open). "DASC Tools" should be an available Toolbox. Within DASC Tools, double click "DASC Time Calculator".
6. The image below should appear.
    a. Input Site is the new site of interest and defaults to "proposed_site" which is a number of "test sites" to demonstrate the function of the tool.
    b. Edited_Veg_Polygons is the layer used to determine what vegetation is within the Input Site. Use "Edited_Veg_Polygons" as the default.
    c. The "Totals" field is the location where the Table of Totals will save to (must be an Arcmap geodatabase*). The default is to overwrite the table present within the DASC database.
    d. The "Predicted Times" field is the location where the Removal Times Layer will be saved (must be an Arcmap geodatabase*). The default is within the DASC database.



7. If a red X appears next to Totals and Predicted Times it is because ArcMap is set to not over-right output files. You will need to change this setting in order to run the tool.
    a. Select Geoprocessing > Geoprocessing Options from the Menu bar
    b. Click the check-box next to "Overwrite the outputs of geoprocessing operations"
8. Click Ok to run the DASC tool.
    a. It should take between 2-3 minutes to run, depending on computer processing speed.

9. Close the dialog box if it does not automatically close.
10. The new layer “Removal_Times” should be available in the ArcMap Table of Contents.
    a. Right click on it and select open attribute table.
        i. Each row represents a vegetation type within the proposed site.
        ii. Scroll to the right and there will be columns for hauling times, cutting times, and total times (hauling + cutting) for each vegetation type. Times are in hours.
        iii. AVG = average predicted time, LL = lower limit of 95% confidence interval, UL = upper limit of 95% confidence interval.
        iv. Close the attribute table.
11. Right click the “Totals” table and select open.
    a. This shows the total AVG, UL, and LL for the entire proposed site (in hours).